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A mixed uncertainty analysis algorithm based on limit state surrogate and interval grouping strategy

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Abstract

The combined probability and evidence theory based method is studied in this paper to address the uncertainty analysis problem under mixed aleatory and epistemic uncertainties. The key to calculate the belief and plausibility measures of failure (the lower and upper bounds of the precise probability of failure) is to calculate the sub-belief and the sub-plausibility in each focal element of the epistemic uncertainties, which involves at least one global optimization (if the focal elements is fully contained in the safe or failure region) and even more complex analysis (if the focal element is crossed by the limit state boundary). Thus when the number of focal elements is big, the computational burden could be unaffordable.

To address the aforementioned computational problem, the following two strategies are proposed. First, Weighted Least Squares Support Vector Regression (WLSSVR) is used to approximate the limit state function and build the surrogate model. Then during the uncertainty analysis, the call of the expensive limit state function can be replaced by the cheap surrogate calculation. Second, based on the limit state surrogate and its training samples, the focal elements can be quickly classified into two categories. One category includes those focal elements which are crossed by the limit state boundary. The sub-belief and sub-plausibility of each focal element in this category need be calculated separately. The other category includes those focal elements wherein the training samples are fully in the failure region or safe region. It means the limit state boundary may not cross these focal elements. These focal elements are then further grouped into several sub-groups according to their spatial distribution. In each sub-group, a global optimization is conducted to check whether this sub-group is totally in the safe or failure region. If yes, then the sub-belief and sub-plausibility of each focal element in this sub-group can be directly assigned as zero or one. Otherwise, this sub-group is further divided into two smaller groups and the global optimization is conducted in each son group. The previous steps are repeated until the sub-belief and sub-plausibility of every focal element is calculated. Then the total belief and plausibility measures can be obtained. By the grouping strategy, the global optimization need not be conducted in each focal element, so as to effectively reduce calculation burden.

Two examples are used to demonstrate the efficacy of the proposed strategies. With the proposed method, the focal elements cross the limit state boundary can be quickly identified with the training samples and the surrogate model. The results show that the efficiency of the proposed method greatly depends on the sampling strategy during the surrogate modeling and the limit state surrogate accuracy. Besides, the division strategy of the big group into smaller sub-groups for further analysis also affects the analysis efficiency. These issues need be studied further in the future.